

Building a Bridge to the Corn Ethanol Industry

Comparison of Contract Results

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April 12, 2000

Bridge Goals

- Provide industry opportunity to explore business potential
- Take advantage of existing corn ethanol industry infrastructure
- Obtain feedback to guide research for commercialization

Bridge Objectives

- Develop a co-location scenario
- Identify feedstock costs and availability
- Determine capital and operating costs
- Produce a Pro forma and perform sensitivity analyses

Participants

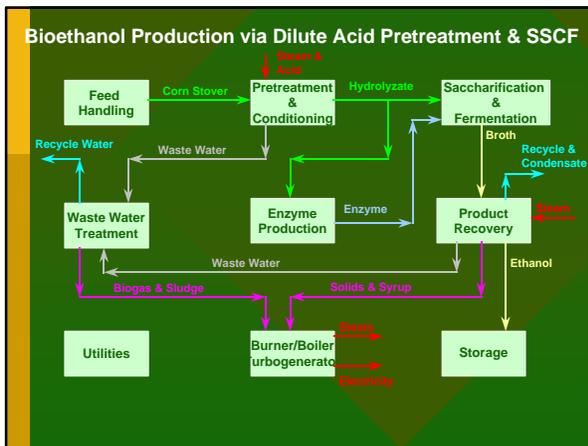
- Merrick/High Plains Ethanol/PureVision Technologies
- Vogelbusch/Chief Ethanol/KAPPA
- LORRE/Williams Energy Services/USDA NCAUR
- NYSTEC/Robbins Corn/Raytheon
- UNDERWAY:
- Weatherly/High Plains Ethanol/SWAN
- Delta T/Chippewa

2 Basic Process Designs

- 3 contractors chose:
 - corn stover feed
 - dilute acid pretreatment
 - enzymatic hydrolysis
 - recombinant *Z. mobilis*
- 1 contractor chose:
 - corn fiber feed
 - hot water pretreatment
 - enzymatic hydrolysis
 - yeast

Site choice and plant size

- 2 of the 3 corn stover plants are co-located with a corn dry mill facility in Nebraska, both rated at around 25MM gallons per year
- The other is a stand-alone facility in New York state, rated at 60MM gallons per year



- ### NREL provided:
- Design Report with Process Flow Diagrams
 - Capital and operating cost database
 - Equipment specifications
 - Technical process support

- ### Most Significant Results
- Only corn fiber (Purdue) process resulted in production costs below the anticipated ethanol selling price
 - All corn stover processes had low or negative returns over the plant life
 - Use of existing plant infrastructure was nonexistent due to recombinant organism

Corn Stover Processes

| | Merrick | NYSTEC | Vogelbusch | NREL |
|-------------------------------|------------|-------------|------------|-------------|
| Plant Type | co-located | stand alone | co-located | stand alone |
| Plant Feed rate (dry ton/day) | 992.07 | 2400 | 936.955 | 2205 |
| Annual Production (MM gal/yr) | 25.7 | 60 | 23.5 | 49 |
| Yield (gal/dry ton) | 74.1 | 71.4 | 72.2 | 63 |
| On-stream hours | 8400 | 8400 | 8400 | 8406 |
| Year for cost basis | 1999 | 1997/1999 | 1999 | 1997 |

Feedstock Costs

| | Merrick | NYSTEC | Vogelbusch | NREL |
|------------------------------|-----------------------|-------------|------------------|-------------|
| Feedstock | corn stover | corn stover | corn stover | corn stover |
| Cost (\$/dry ton) | \$35 | \$35 | \$43 to \$46 | \$25 |
| Cost (\$/gal EtOH) | \$0.47 | \$0.49 | \$0.61 | \$0.39 |
| Cost basis | NE growers/iron Horse | NY growers | NE growers/Chief | |
| Type of System | established | | current | established |
| Feed handling capital (\$MM) | 6.1 | 5.7 | 10.3 | 3.7 |

Contractors' Enzyme Costs

| | LORRE | Merrick | NYSTEC | Vogelbusch |
|------------------------------|--------------------|------------------|------------------|-------------------|
| Enzyme Source | Purchased | Produced on-site | Produced on-site | Assumed Purchased |
| Cost Reference | Cellulase Supplier | PureVision | NREL | NREL |
| Enzyme Cost (\$/gal Ethanol) | \$0.0387 | \$0.20 | \$0.30 | \$0.30 |

Utilities and Co-products

| | Merrick | NYSTEC | Vogelbusch | NREL |
|-----------------------------|--------------|-------------|------------|-------------|
| Steam production | gas | biomass | biomass | biomass |
| Electricity | \$0.035/Kwh | generated | generated | generated |
| Lignin fate | sold | burned | burned | burned |
| Co-product | Methane | electricity | none | electricity |
| Co-product value | \$2.50/MMBtu | \$0.035/Kwh | \$0.00 | \$0.04/Kwh |
| Co-product credit (\$MM/yr) | \$0.33 | \$3.80 | \$0.00 | 3.3 |

Financing/Costing

| | Merrick | NYSTEC | Vogelbusch | NREL |
|--------------------------------|------------|--------|---------------------|-----------------|
| Plant Life (yr) | 20 | 20 | 12 | 20 |
| Depreciation Method | SL | SL | SL | DB |
| Depreciation Term (yr) | 15 | 15 | 15 | 20 |
| Financing | | | | |
| Equity | 0.25 | 0.3 | 0.3 | 1 |
| Interest rate | 0.07 | 0.11 | 0.1 | 7.5 |
| Loan term | 15 | 15 | 15 | 10 |
| Cost escalation | 3% | | 2% for costs | require 10% ROI |
| Other | 10% grants | | no price escalation | |
| Ethanol selling price (\$/gal) | \$1.10 | \$1.15 | \$1.15 | 10% ROI |

Capital and Operating Costs

| | Merrick | NYSTEC | Vogelbusch | NREL |
|------------------------------------|---------|---------|------------|---------|
| Capital (\$MM) | \$79.4 | \$230.0 | \$153.0 | \$227.2 |
| Capital (\$/annual gal) | \$3.09 | \$3.83 | \$6.51 | \$4.64 |
| Annual Depreciation (\$MM/yr) | \$5.3 | \$15.33 | \$10.20 | \$11.36 |
| Capital Charge (\$MM/yr) | \$14.0 | \$40.48 | \$26.93 | \$39.99 |
| Fixed operating costs (\$MM/yr) | \$6.3 | \$8.9 | \$2.7 | \$7.3 |
| Variable operating costs (\$MM/yr) | \$17.6 | \$38.3 | \$25.2 | \$28.7 |

How the processes were compared

- Each contractor used different pro formas (economic assessment tool)
- NREL engineers used a common capital charge factor to compare the different contractor processes
- Normalizes owner equity and other loan factors, and return on investment to 10%

Contractors' Base Case Process

| | Merrick | NYSTEC | Vogelbusch | NREL |
|---------------------------------|--------------------|-----------------------------|--|--------|
| Contractors' Pro forma results | 1% annual avg. ROI | \$0.604MM cumulative profit | \$22MM avg annual loss (-14.5% annual ROI) | |
| 10% ROI | | | | |
| Annual Production Cost (\$/gal) | \$1.46 | \$1.40 | \$2.33 | \$1.48 |

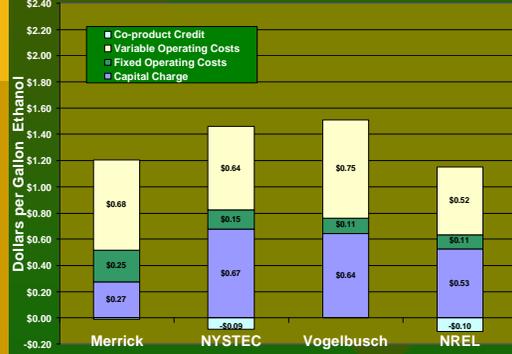
Ethanol Cost with minimum 10% ROI
Contractors' Base Case



Contractors' Improved Process

| | Merrick | NYSTEC | Vogelbusch | NREL |
|---|-----------------------------|---|--|-----------|
| Improvements | Reduce capital costs by 50% | Increase value of electricity credit by 35% | Combined 20% yield increase, \$10/ton feed cost reduction, 0.20/gal enzyme cost reduction, 42% capital cost reduction, loan rate reduction | Year 2005 |
| Contractors' Pro forma results | 21% ROR | 18.262MM cumulative profit | \$0.126MM avg annual profit (0.17% ROR) | |
| 10% ROI Annual Production Cost (\$/gal) | \$1.19 | \$1.38 | \$1.51 | \$1.05 |

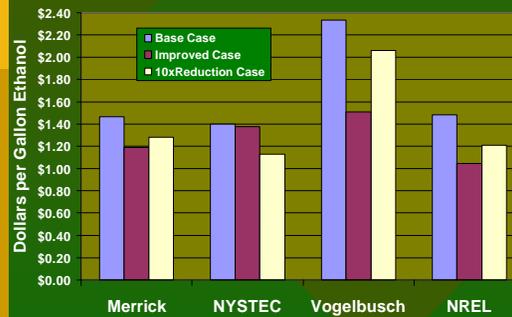
Ethanol Cost with minimum 10% ROI
Contractors' Improved Case



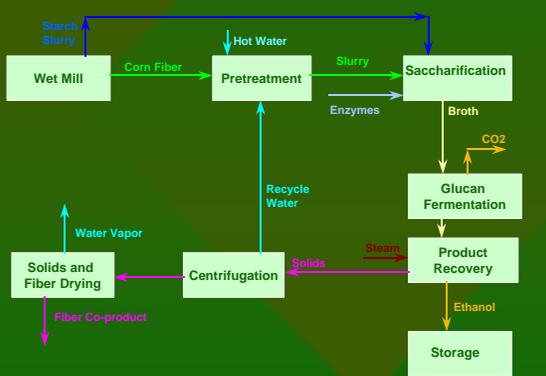
Enzyme 10x Cost Reduction Scenario (NREL)

| | Merrick | NYSTEC | Vogelbusch | NREL |
|---|---------|--------|------------|--------|
| 10% ROI Annual Production Cost (\$/gal) | \$1.28 | \$1.13 | \$2.06 | \$1.21 |

Annualized Cost per gallon with minimum 10% ROI



LORRE Process for Wet Mill Corn Fiber Treatment



Corn Fiber Process Feed

| | LORRE |
|---|--------------------------------|
| Plant Type | co-located with wet mill |
| Location | not provided |
| Process | Hot water/Enzymatic Hydrolysis |
| Plant Feed rate (dry ton/day) | 495 |
| Annual Production (MM gal/yr) | 8.2 |
| Yield (gal/dry ton) | 47.5 |
| On-stream hours | 8400 |
| Year for cost basis | 1999 |
| Feedstock | corn fiber |
| Cost (\$/dry ton) | \$65.00 |
| Reported Cost (\$/gal EtOH) | \$0.55 |
| Calculated Cost (\$/gal EtOH) | \$1.37 |
| Cost basis | Carbohydrate component only |
| Feed handling area installed capital (\$MM) | \$0.05 |

Corn Fiber Process Costs

| | LORRE |
|------------------------------------|---------------------------|
| Steam production | assumed \$1.8-5 per MMBtu |
| Electricity | purchased - not provided |
| Lignin fate | none |
| Plant Life (yr) | 10+ |
| Depreciation Method | SL |
| Depreciation Term (yr) | 10 |
| Financing | not provided |
| Ethanol selling price | \$1.00 |
| Co-product credit (\$MM/yr) | fiber at \$65/dry ton |
| Costs | |
| Capital (\$MM) | \$9.0 |
| Capital (\$/annual gal) | \$1.10 |
| Annual Depreciation (\$MM/yr) | \$0.90 |
| Capital Charge (\$MM/yr) | \$1.62 |
| Fixed operating costs (\$MM/yr) | not provided |
| Variable operating costs (\$MM/yr) | not provided |

Corn Fiber Process Cases

| | LORRE |
|-----------------------------------|------------------------------------|
| Contractor's Base Case | |
| Reported value | .73 to .82 |
| Contractor's Improved Case | |
| Improvements | Lower fiber value/cost to \$40/ton |
| Reported value | 0.58 to .67 |
| 10x reduction in cellulase costs | |
| Cellulase enzyme Source | Purchased for \$0.0387/gal |
| Reported value | .73 to .82 |

Co-location Benefits...

- Land
- rail, load-out facility
- lab/operator experience
- permitting in place

Wash-outs...

- Infrastructure sharing
- low capital cost
- ready feedstock
- enzyme prices available

Biggest Cost Impacts to Process

- Feed cost
- Capital cost
- Yields
- Debt/Equity ratios
- Ethanol selling price

Subcontract Value

- Enzymatic process is not yet cost effective
- Survey of feed prices and availability
- Check of NREL capital costs
- Feed handling design
- Some enzyme costing/design
- Wastewater treatment design

Contractors' Recommendations for Research

- Get GMO acceptance
- Reduce capital costs
- Find market for lignin
- Determine *Z. mobilis* hardiness for production
- Do pilot scale work with stover
- Reduce feed costs

Were the Goals of the Bridge Achieved?

| | LORRE | Merrick | NYSTEC | Vogelbusch |
|---------------------------------|-------|----------|--------|-------------------|
| Goals: | | | | |
| Provide opportunity to industry | Yes | No | No | No |
| Use plant infrastructure | Yes | No | No | No |
| Obtain feedback | Yes | Yes | Yes | Yes |
| Objectives: | | | | |
| Identify feedstock costs | Yes | Yes | Yes | Yes |
| Identify feedstock availability | Yes | Yes | Yes | Yes |
| Determine equipment needs | Yes | Feed/WWT | Feed | Feed/Distillation |
| Determine costs | Yes | Yes | No | Yes |
| Pro forma/sensitivities | Yes | Yes | Yes | Yes |

Contractors' Implementation Plans

- Purdue is planning a 1/9th scale pilot plant to demonstrate hot water on fiber
- NYSTEC plans to pursue business plant for a corn ethanol plant
- Merrick/High Plains and Vogelbusch/Chief have no plans